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Environmental impact of rabbit meat: The effect of production efficiency

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ABSTRACT

The aim of this trial was to analyse the environmental impact of the rabbit production system, through a cradle to-slaughterhouse gate using a life cycle approach. Since in a rabbit farm the production efficiency depends on the feed conversion and quantity of meat produced, scenarios characterized by different slaughter weights and dissimilar level of mortality during the fattening phase were hypothesized.

Climate change determined in the standard rabbit resulted in 3.86 kg CO_2 eq/kg live weight, slightly higher than that of broilers and not different from that of pork. High and Low mortality scenarios resulted in impact changes from +5.22 and −2.31%, respectively, compared with the standard system. An increase of environmental impact values (up to 36%) was registered when live weight enhanced from 2.7 to 2.9 kg for standard and heavy rabbits. The results obtained underline the strict link between the ability to convert feed into meat and the environmental sustainability of meat production also in the rabbit system.

1. Introduction

Rabbit meat is considered to be good product with a great nutritional value and dietetic properties; it is characterized by high protein content, a low concentration of fat with a high degree of unsaturated fatty acids and low sodium and cholesterol levels (Hernández & Dalle Zotte, 2010; INRAN, 2017).

Europe, Italy and Germany produce heavy rabbits with an average carcass weight (CW) of 1.5–1.6 kg, which involves longer rearing cycles and, consequently, higher feed intake and excretion, whereas Spain and France produce lower CW (1.21 and 1.42 kg, respectively; Petracci et al., 2018).

Feed efficiency, mostly expressed as feed conversion ratio (FCR) is a key indicator by which to predict the economic success and the environmental sustainability of the farming system. The close link between environmental sustainability and capacity to convert feed in food is underlined by many studies. In a heavy pig production system, the emissions and excretions per live weight (LW) are worse in the last finishing phase due to a sensible decrease of efficiency of feed conversion (Bava, Zucali, Sandrucci, & Tamburini, 2017). Similar results were obtained also in poultry production: the worse FCR observed in heavy broilers in comparison with light and medium ones is probably the main cause of the higher global warming potential per kilogram of CW of the Italian broiler (Cesari et al., 2017). Nijdam, Rood, and Westhoek (2012) affirmed that animals with high feed conversion efficiencies, such as poultry, score minor values of climate change and acidification potential, whereas beef has the highest values.

Maertens (2010) reported that the average FCR of rabbit during the fattening period resulted in 2.94, a value higher than that generally registered in broiler chickens (less than 2).

In fact, rabbits (as monogastric herbivores) require a diet characterized by a high level of fibre that contributes significantly to the poor feed conversion. The same authors showed that the important reduction of FCR in the last 15 years has translated into a drop in nitrogen and phosphorus output per rabbit of approximately 10% with a positive effect of reducing air and water pollution.

Moreover, the low carcass yield compared to broilers (58 vs 70% on average, respectively) negatively influences the production expressed per kilogram of rabbit carcass.

The livestock sector, by making extensive use of agricultural raw materials and producing pollutants from livestock breeding and the management of grain production, contributes in a non-negligible manner to environmental pollution. This sector has been called upon to assess objectively the efficiency of its production processes in order to develop adequate business management procedures that minimize the environmental impact of different animal productions.

Different studies on monogastric species (Bava et al., 2017; Cesari et al., 2017) reported that the main contribution to environmental impacts was feed production, in particular purchased protein feeds, especially soybean meal associated with deforestation-related emissions.

In recent years, several studies have evaluated the environmental

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impact of beef, pigs, poultry and some aquaculture production with a life cycle approach (Bragaglio et al., 2017; Marco et al., 2017; McAuliffe, Chapman, & Sage, 2016; Pelletier, 2008), but few studies (Aubin, 2014; Cesari, Negretti, Zucali, Bava, & Toschi, 2015; Zened et al., 2013) have been carried out in rabbit meat production. Only the latest research underlines the possibility to reduce environmental impacts of meat production by applying different management strategies. In fact, these authors showed a positive effect on the most important impact categories of rabbit meat production with an administration of restricted ration from weaning to slaughter compared to ad libitum ration without reducing rabbit performance.

Therefore, the aim of this trial was to analyse the environmental sustainability of the rabbit production system through a cradle-to-slaughterhouse gate using a life cycle approach.

Since in a rabbit farm the production efficiency, and consequently its environmental impact, depends on the FCR and the quantity of meat produced, scenarios characterized by dissimilar level of mortality during the fattening phase and different rearing cycles (and consequently different live weight at slaughter) were hypothesized.

2. Material and methods

An attributional life cycle assessment (LCA) methodology was used in order to evaluate the environmental impact of rabbit meat production an intensive rearing system.

2.1. System description

Considering the high variability of parameters which characterized European rabbit production and the strictly link between productive efficiency and some important rearing factors (length cycle, slaughter weight, mortality and morbidity rate, feed efficiency, etc), average data of productive parameters were acquired from international literature (Table 1) in order to define a reference scenario that allows underlining of relationship between production efficiency and environmental impact.

The standard rabbit rearing system described (Table 2), considered representative of European rabbit production, was organized in two different housing units: breeding farm and fattening farm.

This breeding system was characterized by 1000 units of breeding with 87.4% of replacement rate of does and 62 weaned rabbits/does per year. The mortality rate of reproductive does was 5% and the live weight of does slaughtered was 4.6 kg.

The growing rabbits were slaughtered at 79 days of age with a body weight of 2.70 kg and a dressing percentage of 58%. Moreover, four different scenarios were considered, depending on mortality rate during growing phase (mortality scenarios: Low 5% and High 20%) and on slaughter weight (LW scenarios: Light 2 kg and Heavy 2.90 kg).

The feeding impact of rabbit meat production was calculated considering three different diets (lactating, reproductive and fattening diets) formulated to meet the nutritional requirements for all rabbit categories (De Blas & Mateos, 2010). In particular, the crude protein of lactating and reproductive diets was 18.5 and 16.0%, respectively, whereas the crude protein of the diet offered to fatteners was 15.6%.

2.2. System boundaries, allocation and LCA inventory

The system boundaries included the entire life cycle of rabbit meat production to slaughterhouse phase. All direct and indirect inputs and emissions arising from the production and processing of feeds and energy sources were considered. In accordance with Pelletier, Ibarburu, and Xin (2014), production and maintenance of infrastructure, such as equipment and buildings, were not included. Similarly, animal drugs were not considered in the assessment. The details of the system boundaries are presented in Fig. 1.

In order to calculate the environmental impact, it was hypothesized that manure produced by all breeder and fattening animals was utilized as organic fertilizer for corn production. The emissions arising from corn grain production were considered.

The majority of feeding ingredients (Table 3) came from European countries, whereas molasses cane originated from Thailand. Additionally, soybean oil and soybean meal derived from Brazil and from Europe (80 and 20%, respectively).

Direct land use change (LUC) for soybean meal and soybean oil was considered in the assessment using the value reported by the Agri-footprint database (Soybean, at farm/BR Economic, Blonk Consultants, 2014). Transports of feeds and animals were included in the calculation.

At farm gate the impact was economically allocated between the production of LW and corn grain, considering economic values of 2 € kg/LW and 180 €/t, respectively.

The environmental impacts at slaughterhouse gate were not

Table 1
Inventory data used to LCA analysis and data sources.

Item	Unit	Value	Reference
Replacement rate of does	%	87.4	Xiccato, Trocino, Fragkiadakis, & Majolini, 2007
Number of litters/doe/year		7.3	Gidenne, Garreau, Drouilhet, Aubert, & Maertens, 2017
Number of weaned kits/litter		8.5	Gidenne et al., 2017
Number of weaned/doe/year		62	Gidenne et al., 2017
Mortality rate after weaning	%	5–20	Gidenne et al., 2017
Digestibility of diet offered to does	%	65	Zened et al., 2013
Digestibility of diet offered to fatteners	%	59	Zened et al., 2013
Feed intake of lactating does and their kits	kg	18.5	Gidenne et al., 2017
Feed intake of only pregnant does (110 d/year)	kg/d	0.160	Gidenne et al., 2017
Feed intake of young females (365 d/year)	kg/d	0.150	Gidenne et al., 2017
FCR[a] of fattener – standard scenario		2.85	Gidenne et al., 2017
FCR[a] of fattener – Low mortality		2.78	Gidenne et al., 2017
FCR[a] of fattener – High mortality		3.00	Gidenne et al., 2017
FCR[a] of fattener – Light LW[b]		2.72	Maertens, 2010
FCR[a] of fattener – Heavy LW[b]		5.50	Gidenne et al., 2017
Body retained protein for fatteners	%	0.35	Xiccato & Trocino, 2010
Body retained protein for does	%	0.40	Xiccato & Trocino, 2010
Phosphorous excretion/doe/year[c]	kg	0.852	Maertens, Cavani, & Petracci, 2005
Phosphorous excretion/fattener/year	kg	0.028	Maertens et al., 2005
Electricity	kWh/t LW[b]	270	Zened et al., 2013

[a] Feed Conversion Ratio expressed as g feed intake (as fed) per g weight gain.
[b] Live weight.
[c] Value calculated considering breeding and young female.

Table 2
Characteristics of standard fattening system and of different scenarios.

Item	Mortality (%)	Age at slaughter (d)	FCR[a]	LW[b] at slaughter (kg)	Dressing out[c] (%)	Meat production (kg)
Standard	10	79	2.85	2.70	58.0	92,237
Low mortality	5	79	2.77	2.70	58.0	94,665
High mortality	20	79	3.00	2.70	58.0	87,383
Light LW[b]	10	65	2.72	2.00	56.0	65,968
Heavy LW[b]	10	93	5.50	2.90	59.0	100,778

[a] Feed Conversion Ratio expressed as g feed intake (as fed) per g weight gain.
[b] Live weight.
[c] Carcass weight/Live weight *100.

allocated, but they were entirely attributed to rabbit meat, the unique production of the system. Waste from slaughterhouse (blood, fur and viscera) were not considered because of their negligible economic value. The weight of dead rabbits during the fattening cycle was excluded from the total LW at farm gate.

2.3. Emission estimation

The number of animals reared was calculated as average annual population as suggested by IPCC (2006) and considering the following lifetime cycles: 365 d for breeding does and 110 d for only pregnant does. For growing rabbits, the lifetime cycle was 49 d for the Standard, Low and High mortality scenarios, 35 d for the Light LW scenario and 63 d for the Heavy LW scenario.

Methane, nitrogen oxide, ammonia and phosphorous emissions were estimated for each animal category. Enteric methane emissions were considered using data from ISPRA (2016). Manure methane emission was calculated using the equation proposed by IPCC (2006).

Volatile solid excretion was calculated using the formula no. 5 from LEAP (2014) and was predicted using data of feed intake obtained from Gidenne et al. (2017), and the ash content in the manure came from AGRIBALYSE® (2016). Additionally, diet digestibility came from Zened et al. (2013; 59 and 65% for fatteners and does respectively).

Nitrogen excretion was calculated starting from dry matter intake, protein content of the ration and nitrogen retained by animals following the indication of Xiccato and Trocino (2010), which suggested values of N retained of 0.35% for fattening rabbits and 0.40% for breeders.

Ammonia and nitrous oxide emissions from animal housing and manure management were calculated using the TIER 2 equations of EEA (2009) on the basis of total N excreted by animals. The N emission factors, as a proportion of total ammonia nitrogen, were specified for solid manure and each step of manure handling.

Ammonia and NO_x emitted during manure spreading on corn were estimated according to EAA guidelines (2009). The amount of N leached was estimated following the IPCC (2006) model. To estimate emissions of PO_4^{3-}, the amount of phosphorus lost in dissolved form to surface water (run-off) and leached was considered as proposed by Nemecek and Kägi (2007), considering P excretion of each animal (0.028 kg/year and 0.852 kg/year, for fattening and breeders rabbit respectively; Maertens et al., 2005).

Carbon dioxide (CO_2) emissions from fuel combustion were estimated on the basis of fuel consumption in all processes of the farming system. Emissions occurring during field operations for corn cultivation were estimated by modifying the processes of the Ecoinvent (2013) database. Emissions from livestock respiration and the variation in soil carbon stocks were not taken into consideration.

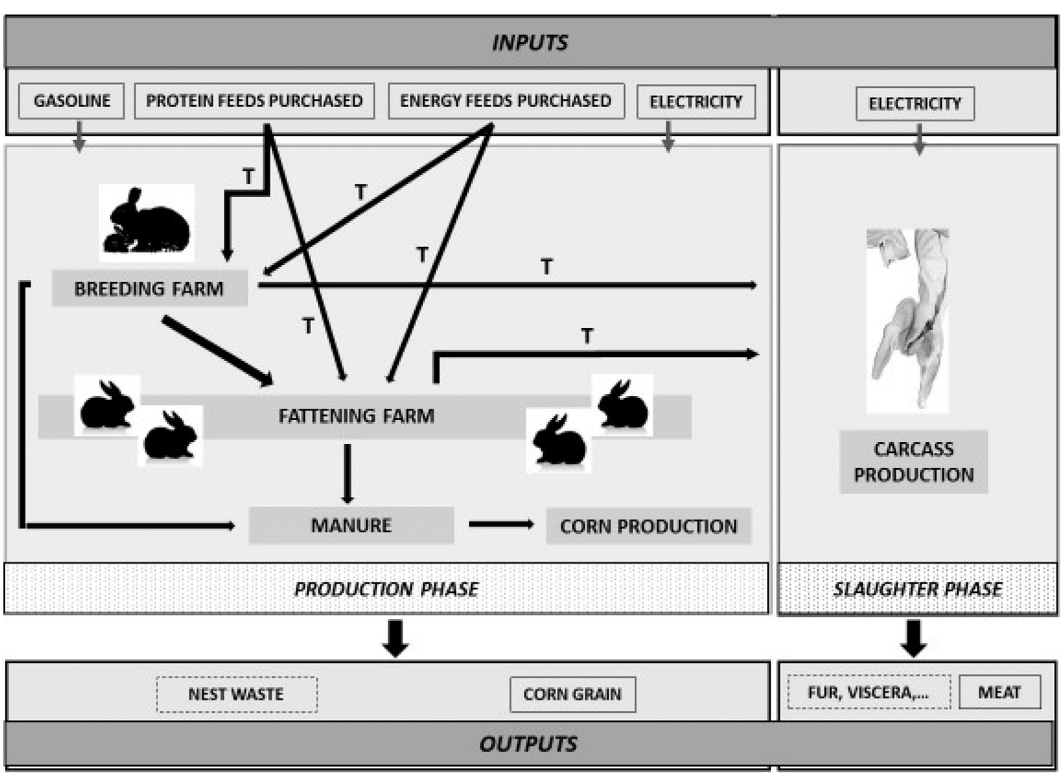

Fig. 1. System boundaries (T = transportation; dashed lines = items out of the system).

Table 3
Origin and percentage of the feed ingredients in the feeding rations.

	Country of origin	Amount (t/year)	Diets		
Feeds			Lactating (%)	Reproductive (%)	Fattening rabbits (%)
Alfalfa meal	Europe	196	22.0	34.0	30.0
Barley	Europe	132	22.0	10.0	20.0
Wheat bran	Italy	135	18.0	23.0	20.0
Beet pulp	Europe	85.7	9.00	10.0	14.0
Sunflower meal (32% CP[a] on DM[b])	Europe	48.3	11.0	7.00	6.00
Molasses cane	Thailand	10.2	1.50	1.50	1.50
Soybean meal (48% CP[a] on DM[b])	Brazil/Europe	50.4	13.0	6.00	6.00
Soybean oil	Brazil	7.50	2.00	–	1.00
Wheat straw	Europe	4.60	–	7.00	–
Minerals & vitamins	Europe	10.2	1.50	1.50	1.50

[a] Crude Protein.
[b] Dry Matter.

The emissions related to the production chains of commercial feed materials (from crop growing to feed factory processing), chemical fertilizers, pesticides, diesel and electricity used in the integrated farming system were quantified mainly using data from the Ecoinvent V3 (2013) and Agri-footprint (Blonk Consultants, 2014) databases.

2.4. Impact assessment and functional unit

Within the life cycle impact assessment, the following impact categories were considered for evaluation: Climate change, Ozone depletion, Human toxicity, cancer effects Human toxicity, non-cancer effects Particulate matter, Ionizing radiation HH, Ionizing radiation E (interim), Photochemical ozone formation, Acidification, Terrestrial eutrophication, Freshwater eutrophication, Marine eutrophication, Freshwater ecotoxicity, Land use, Water resource depletion, Mineral and fossil renewable resource depletion. The characterization factors considered were those from ILCD 2011 Midpoint V1.03. For land and energy use, estimations used also the Ecological Footprint V1.01 and Cumulative Energy Demand methods respectively in order to easily compare the results with other studies.

The functional unit (FU) was 1 kg of live weight at farm gate and 1 kg of CW at slaughterhouse gate. In order to compare the results of the study with other environmental impact assessments on other meat products, an FU based on protein content was used. Data of meat protein content (20.3% of boneless meat) was achieved from Hernández and Dalle Zotte (2010). The boneless meat was pared to 63.8% of CW as suggested by Petracci et al. (2018).

2.5. Scenario analysis

2.5.1. Low and high mortality scenario analysis

In growing rabbits, digestive troubles are the main cause of morbidity and mortality that could sometimes reach very high values (20–30%).

In order to determine the impact of different percentage of mortality during the fattening phase on rabbit meat production, two scenarios were hypothesized that are characterized by the same live weight (2.7 kg) and age at slaughter (79 d), but dissimilar levels of mortality: 5% (Low mortality) and 20% (High mortality). The number of rabbits produced per doe cage was 60.5 in the scenario characterized by Low mortality and 55.8 in the High mortality scenario.

2.5.2. Light and heavy live weight scenario analysis

In Europe, the production of rabbit meat is characterized by important differences in term of slaughter (from 2 to 2.7 kg); in the north of Italy, moreover, rabbits are slaughtered at around 3 kg.

For this reason, the aim of this scenario analysis was to study the effects of different rearing period, and consequently dissimilar live weight at slaughter and FCR, on the environmental impact of rabbit meat production.

The Light LW scenario presented a body weight of 2 kg at slaughter (65 days of age) and a dressing percentage of 56%, whereas the Heavy LW scenario had a higher live weight (2.9 kg at 93 days of age) and greater dressing percentage (59%).

For this analysis, it was considered that the number of rabbits produced per year remains constant regardless of the length of the fattening cycle.

The mortality rate in these scenarios was considered the same as that of the standard scenario (10%).

3. Results and discussion

3.1. Impacts of rabbit meat production at farm gate

Environmental impacts of the rabbit production system are shown in Table 4. In the international literature, impact evaluations linked to rabbit production are lacking and it is often difficult to make comparisons between results of different studies because of dissimilar FU (LW or CW), carcass yield and final weight at slaughter.

In the present study, Climate change determined in the standard rabbit-rearing system resulted in 3.86 kg CO_2 eq/kg LW, a value higher than that reported by other authors (Aubin, 2014; Salou et al., 2014). Vayssières et al. (2011), instead, in a study on 25 farms in a tropical area, reported a higher average value of Climate change (5.2 kg CO_2 eq/kg LW) and a great variability between data found in different rabbit farms. Additionally, Cesari et al. (2015), in a study on an Italian intensive rabbit farm, reported a higher impact of rabbit production (5.54 kg CO_2 eq/kg LW). This greater value could be explained by the lower productive performance registered in breeding and growing phases (fewer rabbits sold per doe per year and worse FCR) in comparison with data documented in the present study.

The impact on the Land use category, using the ILCD method, is indicated as ‘Carbon deficit’, which is the expression of changes in soil organic matter. In our study, it resulted in negative value because of the high contribution of alfalfa meal used in the feed, which increases the carbon stock in the soil in comparison with arable crops (Little et al., 2017). Expressing land use as land surface (m^2) used for on-farm and off-farm activities resulted in 12.5 m^2/kg LW, higher than the value found by Zened et al. (2013).

3.2. Impacts of rabbit meat production at slaughterhouse gate

When the environmental impact of the rabbit production system was expressed for kilograms of CW as FU, the values increased for all impact categories by 49.1% on average for the inclusion of the slaughterhouse phase and for the low carcass yield of rabbits (58%). In

Table 4
Environmental impacts of rabbit production system, expressed per kg of live weight, carcass weight, bone free meat and protein.

		LW[a]	CW[b]	Bone free meat	Protein
Climate change	kg CO_2 eq	3.86	7.55	11.5	51.4
Ozone depletion	kg CFC^{-11} eq	$1.53*10^{-7}$	$3.12*10^{-7}$	$4.76*10^{-7}$	$2.13*10^{-6}$
Human toxicity, cancer effects	CTUh	$1.11*10^{-7}$	$2.20*10^{-7}$	$3.36*10^{-7}$	$1.50*10^{-6}$
Human toxicity, non-cancer effects	CTUh	$5.30*10^{-6}$	$1.00*10^{-5}$	$1.53*10^{-5}$	$6.84*10^{-5}$
Particulate matter	kg $PM^{2.5}$ eq	0.004	0.007	0.011	0.048
Ionizing radiation HH	kBq U^{235} eq	0.37	0.75	1.14	5.11
Ionizing radiation E (interim)	CTUe	$1.22*10^{-6}$	$2.46*10^{-6}$	$3.75*10^{-6}$	$1.67*10^{-5}$
Photochemical ozone formation	kg NMVOC eq	0.01	0.02	0.03	0.13
Acidification	molc H^+ eq	0.15	0.28	0.43	1.93
Terrestrial eutrophication	molc N eq	0.65	1.24	1.89	8.43
Freshwater eutrophication	kg P eq	0.0004	0.0008	0.0013	0.0057
Marine eutrophication	kg N eq	0.038	0.072	0.110	0.490
Freshwater ecotoxicity	CTUe	12.9	25.4	39	173
Land use	kg C deficit	−21	−39	−59	−263
Water resource depletion	m^3 water eq	1.13	2.42	3.7	16.5
Mineral, fossil and renewable resource depletion	kg Sb eq	$4.18*10^{-5}$	$7.99*10^{-5}$	$1.22*10^{-4}$	$5.45*10^{-4}$

[a] Live Weight.
[b] Carcass Weight.

this study Climate change resulted in 7.55 kg CO_2 eq/kg CW, a value higher than that reported by Zened et al. (2013; 4.01 kg CO_2 eq/kg CW; Table 4). This difference could be due to the lower level of soybean meal used by these authors (5.12 and 0.81% for reproductive and fattening diets, respectively), whereas in our study the diets were characterized by a higher percentage of soybean meal (13.0, 6.0 and 6.0% for lactating, reproductive and fattening diets, respectively).

Energy use was similar (44.8 MJ/ kg CW) to the value found by Zened et al. (2013), whereas Acidification and Eutrophication resulted in slightly higher data than reported in the same study. Acidification potential, mainly dependent from ammonia emission and as a consequence of nitrogen excretion, could be greater in our study because of the higher protein content of diets and the different protein digestibility of raw materials.

The slaughterhouse phase impacted from 0.19 to 11.8% for different impact categories. For Climate Change this phase loaded 3.52%, equal to 0.27 kg CO_2 eq/kg CW; this result is similar to the findings of Reckmann and Krieter (2015) and Cesari et al. (2017) in studies on pig and broiler production (0.21 and 0.16 kg CO_2 eq/kg CW, respectively). Also Zened et al. (2013) found a low impact of slaughterhouse in rabbit (less than 10% in all categories).

Comparing the value of Climate change, expressed as CW (Table 4), with data found on other species, it is clear that the environmental impact of rabbit production is higher than chicken production, which varies approximately from 2.5 to 5.5 kg CO_2 eq (Bengtsson & Seddon, 2013; Cesari et al., 2017; Pelletier, 2008). This is due to the lower carcass yield of rabbits compared to broilers (58 vs. 70%, respectively), which is a critical point of rabbit meat production.

The largest contribution to Climate change came from CO_2 (71.2%), which resulted from crop production due to fossil fuel use and transportation, followed by CH_4 emission derived from manure storage and management (6.97%). In the rabbit farm, ammonia emissions, arising from the manure management (i.e. the animal housing, manure storage and treatment, and land spreading), were responsible for 92.7 and 94.8% of Acidification and Terrestrial eutrophication.

According to studies on broiler production, the fattening period is the phase that makes the most important contribution to many environmental impact categories of rabbit production. In fact, the fattening stage loaded 62.6% for Climate change and 68% for energy use, expressed as Mineral, fossil and renewable resource depletion; for Acidification and Freshwater eutrophication, this phase contributed 67.7 and 59.0% respectively.

Fig. 2 shows that the off-farm contributions had in important role in impacting different categories. In particular, the production of purchased feeds resulted in the most impact (from 57.6 to 97%) for the following categories: Climate change, Ozone depletion, Human toxicity, Ionizing radiation, Photochemical ozone formation, Freshwater ecotoxicity, Water resource depletion and Mineral, fossil and renewable resource depletion. Also, in the study by Vayssières et al. (2011), the most important contribution to Climate change was represented by the production of feeds (65%).

Considering separately the contribution of purchased energy and protein feeds, it is interesting to notice that for many impact categories energy feeds had the main impact, contrary to the results on broiler production (Cesari et al., 2017), which is explained by the low protein content.

Regarding the Climate change the impact derived from protein feeds (39.8%) was higher than that caused by purchased energy feeds (30.8%), probably due to the effect of land use change because soybean production was associated with some deforestation-related emissions. Even if in this study soybean meal was utilized at a moderate level (13, 6 and 6% for lactating, reproductive and fattening diets, respectively), the use of this raw material would have been another weak point in the environmental sustainability of rabbit meat production as it is for other meat production (i.e., poultry meat; Cesari et al., 2017; and pork meat; Bava et al., 2017).

In rabbit production, the use of different protein feeds, not only protein from soybean, allowed the reduction of impacts due to LUC of soybean meal and oil. The most important percentage of protein feed for rabbit production, during the fattening and breeding periods, was alfalfa meal, followed by sunflower meal and soybean meal. The impact of soybean meal production in the country of origin (Brazil) resulted in a 29.0% contribution to the Climate change category; this high contribution is due to the impact of LUC estimation, which is 2.19 kg CO_2 eq/kg CW.

Moreover, the production of purchased feeds (both energy and protein feeds) accounted for 53.6% of Freshwater eutrophication. For the impact categories Particulate matter, Acidification and Terrestrial eutrophication, the main single contributor was emissions from manure in the barn and during storage, ranging from 34.5 to 39.7%.

On the contrary, the on-farm activities gave a smaller contribution than off-farm activities (Fig. 2) for the most impact categories except for Particulate matter, Acidification and Terrestrial eutrophication. For these categories, ammonia emission from manure spreading on corn crops is the most important factor. For Marine eutrophication, crop production on the farm is the largest contribution due to nitrate emissions (i.e., the major substance considered in this category).

In order to compare the impacts that originate from the different species, data were converted from carcass to bone-free meat and to meat protein content.

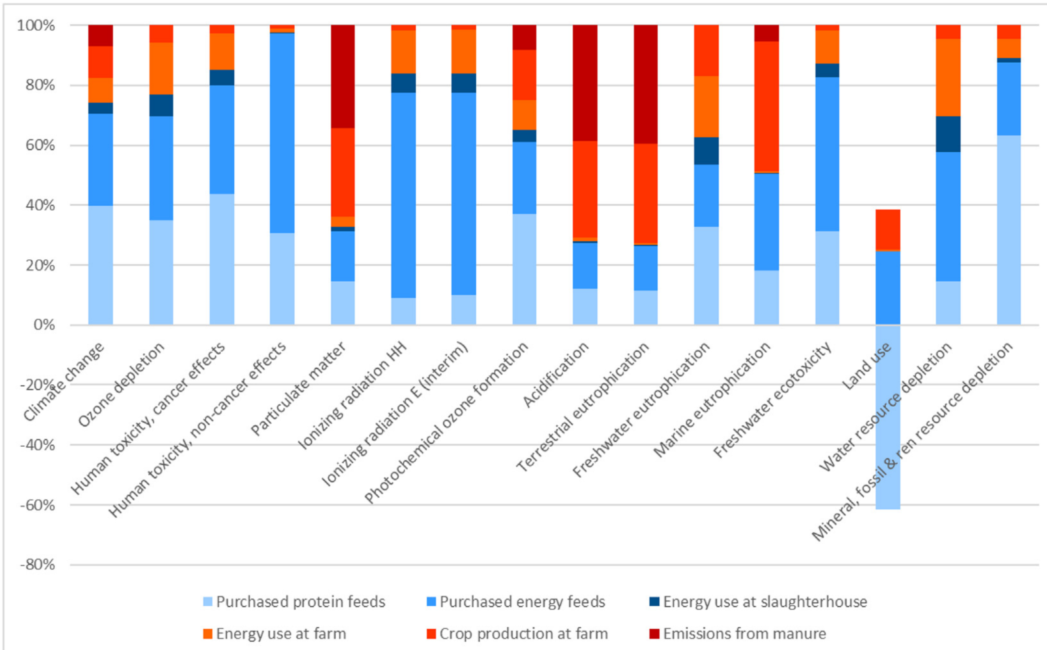

Fig. 2. Contributions of different compartments to environmental impact categories (per kg of carcass weight) for rabbit production at slaughterhouse gate. Blue and light blue bars are the off-farm contributions, red and light red bars are the on-farm contributions.

The conversion factor used to convert a carcass to edible meat was 63.8% (Petracci et al., 2018). When comparing the environmental pressure per kilogram of bone-free meat, the value of Climate change detected in our study was 11.5 kg CO_2 eq/kg bone-free meat. This result is similar to the findings of Zucali, Bacenetti, Cesari, Toschi, & Bava, 2018 (In press) in pigs (10.8 kg CO_2 eq) using a percentage of lean meat of 49.2 (Lo Fiego, Franci, & Sirtori, 2017). Moreover, broilers showed the best results with 8.63 kg CO_2 eq/bone free meet (Zucali et al., 2018, In press) considering a factor of 62% (Cavani, Meluzzi, Petracci, & Sirri, 2017).

Considering a protein content of 20.3% in rabbit meat (Hernández & Dalle Zotte, 2010), the Climate change (expressed per kg CO_2 eq/kg of protein) was 51.4. This result is similar to that reported by Nijdam et al. (2012) for pork (20–55 kg CO_2 eq/kg protein) and higher than that registered for chicken (10–30 kg CO_2 eq/kg protein).

3.3. Scenario analyses results

Four different scenario analyses were carried out in order to evaluate the effects of different levels of mortality and length of fattening period, which affect production efficiency, on environmental impacts assessment of rabbit meat production. The results of the scenario analyses are reported in Fig. 3.

Regarding the mortality rate, the best scenario for all environmental impact categories was Low mortality. In fact, this scenario determining the highest quantity of slaughter weight could cause a decrease of the environmental load of rabbit production (estimable from −1.9 to −2.3% for different impact categories), in comparison with the standard rearing system.

Climate change resulting from the Low mortality scenario, in particular, was lower than that registered in the standard farm and in the scenario characterized by high mortality (3.79, 3.86 and 4.04 kg CO_2 eq/kg LW, respectively). The relationship between mortality rate and Climate change is well described in Fig. 4.A, where an increase of mortality, involving a worsening of FCR (Maertens, 2009) and a reduction of carcasses produced, would lead to a proportional worsening of environmental impact.

The mortality rate of rabbits depends on various factors, such as age at weaning, sanitary and immune status of the animals and composition of diets. In order to prevent disease and to achieve a low mortality rate, it is necessary to improve farm management, to enhance hygienic conditions and to use a specific feeding programme during weaning and fattening periods also with the aim of minimizing excretion.

Zened et al. (2013), for example, estimated a mitigation effect of feed restriction that causes a decrease of the mortality rate (from 16 to 8% during the fattening phase) equal to 9% for Climate change, 12% for Acidification and 11% for Eutrophication.

Moreover, Birolo et al. (2016, 2017) observed a reduction of nitrogen excretion, without negative effect on growth and slaughter weight, of rabbits submitted to a moderate feed restriction in comparison with ad libitum feeding.

Changes in terms of the length of the fattening period (Light vs Heavy rabbit) produced the highest variations in terms of environmental impact (Fig. 3); an increase of slaughter weight, in fact, determined higher values of FCR as a consequence of a worsening of daily weight gain.

An increase of environmental impact values (up to 36%) was registered when rabbits' live weights enhanced from 2.7 to 2.9 kg of LW for Standard and Heavy rabbits, respectively. The standard rabbit farm, moreover, showed a lower value of Climate change (3.86 kg CO_2 eq/kg LW) in comparison with other scenarios (4.23 and 5.48 kg CO_2 eq/kg LW for Light and Heavy rabbits, respectively).

Even if dressing percentage increased with the growth of live weight at slaughter (56, 58 and 59% respectively for Light, Standard and Heavy rabbits), data about Climate change, expressed in term of CW, confirm the trend described above.

The most important contributor for many impact categories was represented by feed production and processing in all scenarios.

As shown in Fig. 4.B, the FCR of heavy rabbit was 5.50 kg feed/kg LW, much higher than those of the other scenarios (2.72 and 2.85 kg feed/kg LW for Light and Standard rabbits, respectively). The highest cumulative feed conversion value of heavy rabbit, as reported by Gidenne et al. (2017), depends on the fact that during the last weeks of fattening cycle the FCR, determined week by week, reached very high values (always above 8) due to the strong reduction of growth rate and the deposition of adipose tissue.

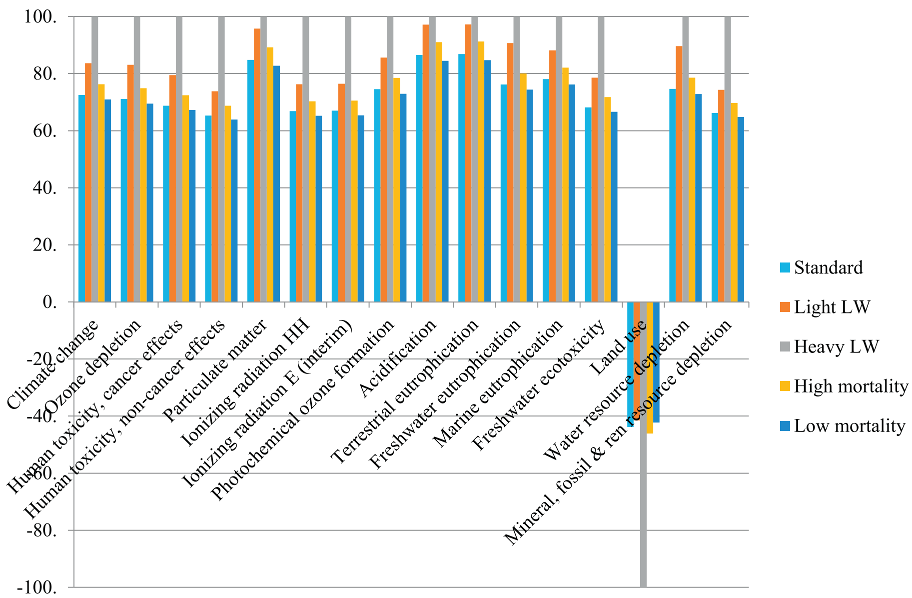

Fig. 3. Comparison of environmental impacts of rabbit production in different scenarios.

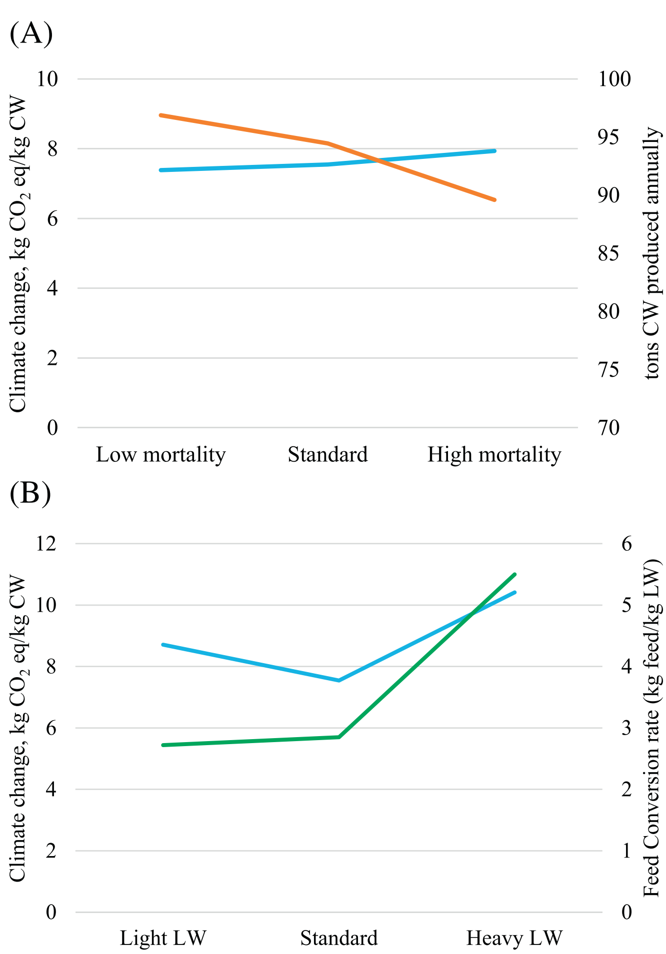

Fig. 4. A: Climate change and carcass weight production in the Standard, Low mortality and High mortality scenarios; B Climate change and FCR in the Standard, Light LW and Heavy LW scenarios.

For Climate change the growth of slaughter weight would not determine an increase of environmental impact; factors such as carcass yield and FCR influenced this result, suggesting that the best choice, also from an environmental point of view, would be a standard rabbit (2.7 kg LW).

In facts, rabbits slaughtered at 65 d registered a value of Climate change higher than that recorded for rabbits slaughtered at 79 d (8.71 and 7.55 kg CO_2 eq/kg CW, respectively); instead, the longer rearing cycle (93 d) determined a high value of Climate change (10.4 kg CO_2 eq/kg CW).

For Particulate matter, Acidification and Terrestrial eutrophication, the worst scenario resulted from light rabbits, which is probably due to the low carcass yield.

4. Conclusions

The success of a meat production system depends on the capability of animals to convert feed into meat; for this reason, the purpose of this study was to analyse the environmental impact of the rabbit production system and to underline the effects of mortality rate and length of rearing cycle.

The results obtained for all scenarios confirmed that the most important hotspot in the environmental impact of rabbit meat production is covered by feed, as reported by other studies on different species.

The impact of soybean meal, in particular, was high, even if rabbit diets were characterized by the use of different protein feeds such as alfalfa and sunflower meals. Also, different on-farm operations such as manure spreading and crop cultivation made important contributions to some impact categories.

Among the different scenarios tested, the best was that characterized by low mortality percentage in the fattening phase because of better FCR and greater quantity of meat produced.

Considering the worsening of feed conversion during the last weeks of the fattening phase, the scenario characterized by the production of heavy rabbit shows a very high environmental impact, hardly improving with better management strategies.

The results obtained, therefore, underline the strict link between the ability to convert feed into meat and the environmental sustainability of meat production also in the rabbit system.

Despite their herbivore nature, rabbits show an environmental impact slightly higher than that of broiler chickens and not different from that of pork. The possibility to substitute a part of soybean meal with alternative protein feeds (such as sunflower meal, peas, rapeseed, etc.) could decrease the environmental impact of rabbit production, allowing

a producer to compensate the higher feed conversion and the lower slaughter yield.

The mortality rate could be considered an important factor not only to evaluate productive results, but also to measure the environmental efficiency of rabbit farms. Therefore, the improvement of management practices, in addition to suitable feeding strategies, could be considered a valid tool to minimize environmental impacts of rabbit production.

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